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Home Canning Processes for Low-Acid Foods

Developed on the Basis of Heat Penetration and Inoculated Packs

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SUMMARY

Calculations from heat-penetration data and the destruction of spores of bacteria of known heat resistance have served to establish processes for the commercial canning of low-acid foods such as meats and vegetables which are subject to spoilage by numerous types of facultative and anaerobic organisms including toxin-producing *Clostridium botulinum*. Home-canning processes generally recommended have been derived by the rather arbitrary extension of commercial processes. Since the home canner is accustomed to using glass jars and since home procedures and steam-pressure equipment differ from commercial, the processes have not been wholly satisfactory. Failure to consider the extra process value of the cooling period for glass jars, together with the practice of adding a large margin of safety to the process time, has resulted in home-canned low-acid products which were often overprocessed and unattractive.

In the development of processes reported here for home canning of low-acid foods, essentially the same research techniques applied with success in the commercial field were employed. Heat-penetration data on meats and vegetables, prepared, packed, and processed under home-canning conditions have been obtained. Adequate processing times were computed on the basis of these data and on the heat resistance of Cameron's putrefactive anaerobe No. 3679, the spores of which are more resistant to heat than those of *Cl. botulinum*. Calculated processes were checked by experimental packs inoculated with spore suspensions of culture No. 3679.

Exploratory work with meat was carried out with chunk pork at temperatures of 240° and 250° F., at different process times. From these data process times were estimated for an inoculated-pack study for processing at 240° F. After incubation at 98.6° for at least 4 months, gross spoilage occurred among inoculated quart jars processed 60 minutes, some spoilage from an 80-minute process, and no spoilage from 90- and 100-minute processes. No spoilage occurred among the uninoculated or control jars similarly treated. A total of 364 quart jars were processed to obtain the heat-penetration and inoculated-pack data for establishing the 90-minute process for pork.

Heat-penetration data were obtained from a total of 74 containers to establish processes for other meats at 240° F. Equivalent processes for other containers were determined from the mean values and their standard deviations calculated from heat-penetration data on 12 each of pint jars, No. 2 and No. 3 cans. These processes were found to be 75, 65,

and 90 minutes, respectively. Processes for beef and boned chicken in quart jars were found to be the same as that for pork. The equivalent process for chicken packed with the bone in quart jars was derived from heat-penetration data on 11 jars, and found to be 75 minutes at 240° F.

Process times at 240° F. for 12 commonly canned vegetables were developed from heat-penetration and bacteriological data on 2,034 pint jars, and heat-penetration data on an additional 1,052 jars and over 700 tin cans. These tests show that when foods are home canned in glass jars the long cooling periods required contribute significantly to the lethal values of processes. With vegetables in pint jars the sterilizing value of the cooling period averaged 50 percent of the total. In quart jars an average of 36 percent of the process value was contributed by the cooling period. In No. 2 and No. 2½ tin cans the corresponding averages were 15 and 11 percent, respectively.

Relatively high values of cooling periods for glass packs did not, however, lead to generally shorter processes as compared with packs in tins. The exhaust given the latter before sealing resulted in higher initial temperatures which tended to balance the sterilizing value of the cooling period for processes in glass containers.

The data obtained have permitted the recommendations of reduction in processes for vegetables in pint jars. With quart jars, lower initial temperatures and greater variability of heat-penetration data have made it necessary to recommend slightly longer processes in a few instances. Processes derived for packs in tin containers are in good agreement with those used commercially.

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Developed on the basis of heat penetration and inoculated packs

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INTRODUCTION

In the preservation of foods by canning the object of the process or heat treatment is to destroy or inactivate all organisms present which are capable of causing spoilage of the canned product under conditions existing within the sealed container during storage. This end is attained when the product is completely sterilized. For practical purposes it may also be attained in the absence of complete sterility if surviving organisms are incapable of proliferating and causing spoilage. Adequate processes must be based, then, upon the time-temperature relations necessary for destruction or inactivation of spoilage organisms in various types of products.

[1] Acknowledgment is made to Mary S. Shorb for early work on bacteriological problems, and to Sophie Marcuse for assistance in the statistical interpretation of results. Thanks are due to Olive Allen, Ruth Bergren, Katherine Ebner, Phyllis Greene, Olivia Hammerle, Alice Harkin, Grace Schopmeyer, Mabel Sterling, and Elizabeth Stokes for valuable assistance in the laboratory work.

In addition to destroying spoilage organisms the process serves to cook the food being canned. When prolonged, it brings about undesirable changes such as the development of overcooked flavors, loss of characteristic texture, and excessive destruction of heat-labile nutrients. As a result, canning technologists have recognized the necessity for carefully planned studies designed to develop processes that are safe and at the same time have the minimum adverse effect upon quality of the canned food.

While numerous types of organisms may cause spoilage of canned foods, only one, *Clostridium botulinum*, is significant as a heat-resistant, food-poisoning type. Since this organism exhibits a resistance to heat comparable to or greater than that of other common spoilage types, it has been accepted as axiomatic by commercial processors and by a majority of those advising on home canning methods that all processes for low-acid products should fulfill the basic requirement of being adequate to destroy the spores of *Cl. botulinum*, the most heat-resistant, food-poisoning type.

Since the period 1918 to 1921, when attention was focused upon the problem by numerous outbreaks of botulism caused by commercially canned products, the industry has recognized the prime importance of canned-food-process studies. Its investigations have resulted in the development of processes which have practically eliminated botulism as a hazard from commercially canned products and reduced over-all spoilage to very low levels.

Outbreaks of botulism caused by home-processed foods continue to occur at the rate of 10 to 12 per year. In a recent publication Esselen (*12*) has summarized reported outbreaks, pointing out that carelessness and faulty canning techniques were largely responsible.

Many investigations have been reported, such as those by Magoon and Culpepper (*19*, *20*), Thompson (*27*, *28*), Bigelow and others (*4*), Burns (*6*), Lancefield (*18*), Jackson (*16*), and Jackson and Olson (*17*). These findings have provided extensive information regarding the rates at which food in cans heats during processing and the effects of such factors as filling temperatures, pack weight, and fluidity, upon those rates. Simultaneously, Bigelow and Esty (*5*), Bigelow (*3*), Weiss (*33*, *34*), Esty and Meyer (*14*), Dickson and others (*11*), Esty and Williams (*15*), and other bacteriologists were determining the thermal-death times of *Cl. botulinum* and of other canned food spoilage organisms.

Bigelow and others (*4*) first solved the problem of applying the above type of bacteriological and physical data to the calculation of thermal processes for canned foods. Ball (*1*, *2*) developed more flexible mathematical formulations for thermal-process calculations. Further modifications have been suggested by Olson and Stevens (*23*) and Schultz and Olson (*24*). Calculated processes have been checked by experimental packs inoculated with bacterial spores of known heat resistance as described by Cameron (*7*) and Williams (*35*).

For the most part, commercial processes are based upon technological data relating to heat penetration in canned foods and the thermal resistance of spoilage organisms. In some instances, according to Cameron (*8*), where less information is available they are based upon analogy with processes for similar products for which the information is adequate, or upon general experience of the industry.

Home-canning processes now generally recommended are not so well founded. To a considerable extent they have been derived by the rather arbitrary extension of commercial processes. This practice does not take into consideration that home and commercial canning equipment and methods differ greatly and that such differences are reflected in the sterilizing values of processes. Slower heating and cooling times with home-canning processes represent probably the greatest difference. Foods home canned in glass containers under steam pressure take a long time to cool, which adds to the lethal value of the process.

Recent studies on home-canning processes have been reported by Nelson and Berrigan (*21*), Nelson and Knowles (*22*), and Cover, Turk, and Kerns (*10*). In the two latter reports the increased sterilizing effect resulting from slow cooling in glass jars was recognized. Esselen and Tischer (*13*) reported home-canning studies in two instances of which processes calculated from thermal-death-time and heat-penetration data were checked by inoculated packs. In spite of the fact that the initial temperatures of the foods canned in these experiments were low and the pressure canner and water were cold at the start, the results indicated that home-canning processes at 240° F. which have been generally recommended for many foods may be more severe than necessary.

The studies reported here were undertaken to gather sufficient information on which to base scientifically sound home-canning processes. Heat-penetration data for meats, poultry, and the commonly canned vegetables have been obtained in experiments in which home-canning procedures and equipment were used. These data have been combined with thermal-death-time data for the computation of adequate thermal processes. Inoculated packs have been used to check the calculated process times.

GENERAL METHOD FOR CALCULATION OF PROCESS VALUES

The general method for calculation of process values is derived from relating time and temperature data given by the thermal-death-time curve of the spoilage organism and the heating-cooling curve of the container of food.

Thermal-Death-Time Curve

A thermal-death-time curve is constructed by plotting on the logarithmic scale of semilogarithmic paper the time in minutes required to destroy the organism against temperature on the linear scale (fig. 1). Bigelow (*3*) noted that thermal-death-time data plotted in this manner yielded curves in which the relation between temperature and logarithm of killing time was, for practical purposes, approximately linear. Ball (*2*) introduced the use of the following symbols to describe such thermal-death-time curves:

F=the time in minutes required to destroy the organism at 250° F.

z=the slope of the thermal-death-time curve expressed as the abscissa interval in degrees Fahrenheit intercepted by the line in passing through one logarithmic cycle on semilogarithmic paper.

The curve can be reconstructed using these two factors. For *Cl. botulinum* in neutral phosphate with a concentration of 30,000

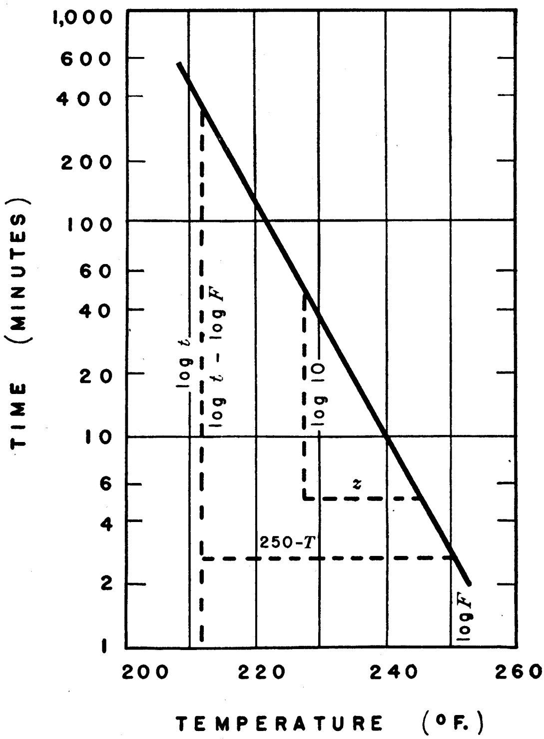

FIGURE 1.—Ideal thermal-death-time curve for *Clostridium botulinum* in neutral phosphate buffer.

million spores per milliliter, Esty and Meyer (*14*) reported data which gave a thermal-death-time curve from which values of F=2.78 and z=18 were later derived. Substantiation of these data with slight corrections was observed by Townsend, Esty, and Baselt (*30*). Their results indicated that the ideal thermal-death-time curve for *Cl. botulinum* in neutral phosphate is more accurately defined by F and z values of 2.45 and 17.6, respectively. Since the values derived from the data of Esty and Meyer have been generally used in canned-food-process studies, they have been used without the later corrections for determining processes reported here.

Lethal Rate

The lethal rate at any given temperature is the ratio of the time in minutes required to destroy an organism at 250° F. to the time in minutes required to destroy it at the given temperature. This ratio is known as F/t. From the thermal-death-time curve (fig. 1) a simple geometric relationship between the sides of similar right angle triangles is expressed by the equation $\frac{\log t - \log F}{\log 10} = \frac{250-T}{z}$ from which $\log \frac{t}{F} = \frac{250-T}{z}$. Given T in degrees Fahrenheit and z, the slope of the thermal-death-time curve, this equation can be solved for $\frac{t}{F}$ from which the reciprocal, F/t, can be found. Schultz and Olson (*24*) gave tables of lethal rates at various temperatures calculated for different values of z.

The lethal rates for $z=18$ are small at Fahrenheit temperatures near 200, but increase rapidly as the temperature approaches 250, as shown by the following tabulation:

Temperature °F.	*Lethal rate*	*Temperature °F.*	*Lethal rate*
190	0.00046	225	0.0409
195	.00088	230	.0774
200	.00167	235	.1468
205	.00316	240	.2783
210	.0060	245	.5275
215	.0114	250	1.0000
220	.0215		

Heating and Cooling Curves

During the processing of a container of food, the temperature increases to a maximum and then decreases on cooling. To illustrate this, a heating-cooling curve may be constructed by plotting temperature against time on coordinate paper (fig. 2). In this bulletin the initial temperature (T_O) is defined as the temperature attained by the food when the temperature in the steam-pressure canner reaches 240° F. and counting of process time begins. Initial temperature is thus distinguished from packing temperature and sealing temperature.

Lethal Rates and Process Values

It is not essential to construct a heating-cooling curve in order to calculate process values from heat-penetration data. The temperature-time data are arranged as illustrated in table 1. For each temperature of the food at definite time intervals, the lethal value, F/t, for that temperature is entered in the table. A lethality curve is constructed by plotting lethal value against time on coordinate paper, as shown in figure 3. The area under the lethality curve may be determined by counting squares or by measuring with a planimeter, as shown in figure 4. This area represents the total lethal value of the heating-cooling period. It is designated as F_O and is a measure of

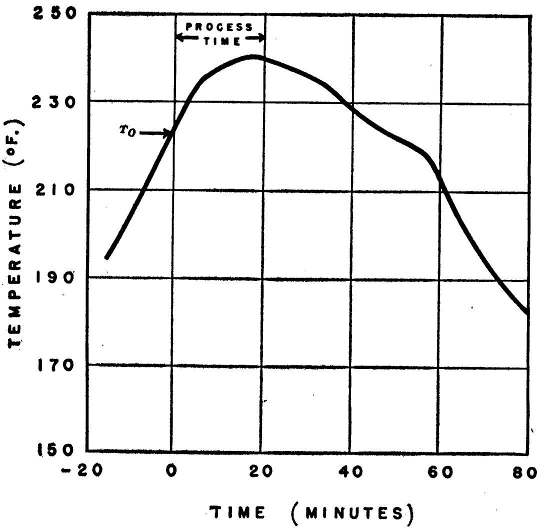

FIGURE 2.—Heating-cooling curve for snap beans processed at 240° F. in a pint jar.

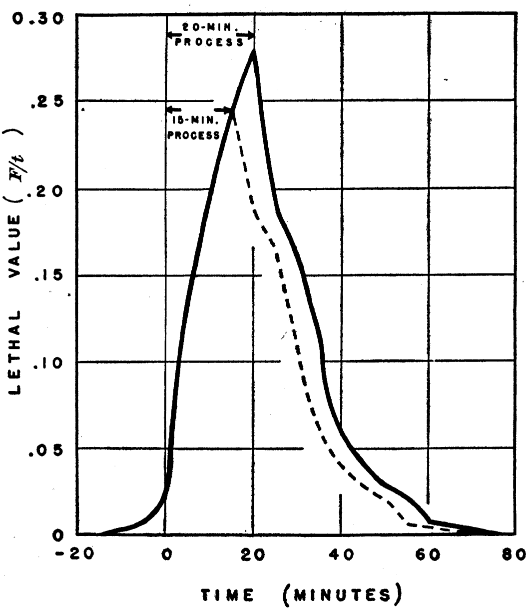

FIGURE 3.—Lethality curve for snap beans processed at 240° F. in a pint jar.

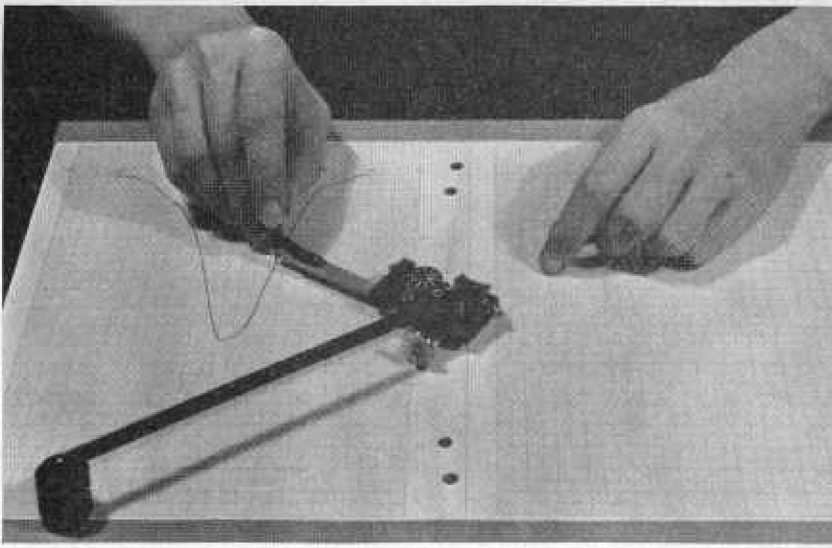

FIGURE 4.—A polar planimeter is used to measure the area under the lethality curve.

the lethal value of the process, hereafter referred to as the process value. The area under the lethality curve in square inches represents the lethal value of the process directly in terms of F_O if the scale of the figure is such that the product of the time and the sterilizing value of 1 square inch equals 1. An adequate process is one yielding an F_O equivalent to the F value of the spoilage organism which the process is designed to destroy.

TABLE 1.—*Jar temperatures and lethal rates during processing at 240° F. and cooling of green beans in a pint jar*

Time	Temperature	Lethal rate	Time	Temperature	Lethal rate
Minutes	°*F.*	*F/t*	*Minutes*	°*F.*	*F/t*
−15	194	0.0008	35	233	0.1140
−10	203	.0024	40	228	.0600
−5	211	.0068	45	225	.0409
0 [1]	222	.0278	50	222	.0278
5	234	.1290	55	220	.0215
10	237	.1900	60	211	.0068
15	239	.2450	65	204	.0028
20	240	.2783	70	194	.0008
25	237	.1900	75	187	.0003
30	236	.1670	80	181	.0001

[1] 0 indicates the beginning of processing time (time when canner reaches 240 °F.).

From the lethality curve (fig. 3) values of process times shorter than the one illustrated may be found by transposing the cooling curve to the left until it intersects the heating curve at the new process-time vertical and measuring the area under the new figure. Time and effort may be saved by simply measuring the area under the heating curve to the left of the process-time vertical to obtain F_H, the value of the heating period, and the area to the right of an equivalent vertical under the cooling curve to obtain F_C, the value of the cooling period, without transposing the curve. The sum of F_H and F_C represents F_O, the total value of the process.

The process values for shorter periods interpolated from experimental data are subject to error when an attempt is made to apply the method over too great a range in process times. Experimentally, the curve for short process times shows that the temperature of the food may remain constant for some minutes or increase slightly before cooling. This would add to the area under the curve and in-

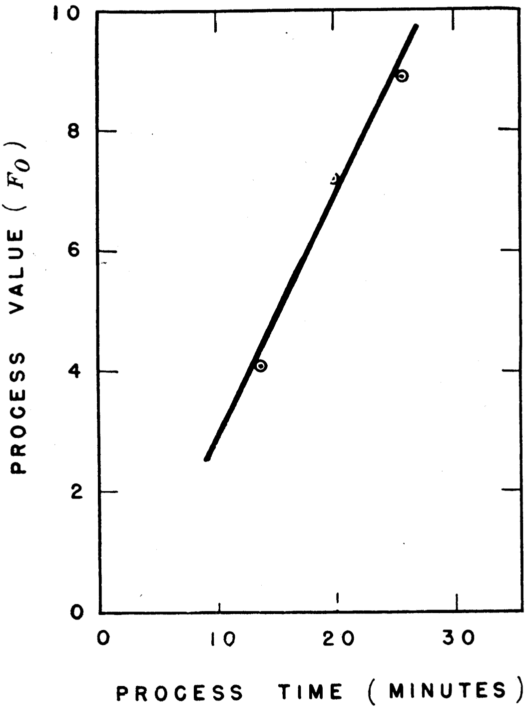

FIGURE 5.—Average process value-process time curve for snap beans processed in pint jars at 240° F.

crease the value of the process. With this increment unaccounted for, the tendency is to obtain longer process times than may be required for a given process value. However, this is more desirable than if the reverse were true, since it tends to yield a greater margin of safety.

When the temperature of the food in the container has reached the canner temperature (240° F.), values of longer processes may be obtained by adding 0.278 (z=18) for each additional minute of the process time.

Determination of Process Times for Specific Foods

A lethality curve is constructed for each container of food at each experimental process time. Process values are obtained for a minimum of three process periods. A process value-process time curve, such as is shown for snap beans (fig. 5), is constructed on coordinate paper by plotting F_0 on the ordinate and process time on the abscissa. From this curve process times can be read for this food which will yield processes adequate to destroy any spoilage organism for which the thermal-death-time curve has a slope of $z=18$ and a known F value. In a like manner, processes for other foods or for spoilage organisms with thermal-death-time curves defined by other z values can be computed.

EXPERIMENTAL METHOD

Foods Studied

Heat-penetration data have been obtained for processing of pork in quart and pint jars, and in No. 2 and No. 3 tin cans; beef and chicken in quart jars; 12 commonly canned vegetables—asparagus, lima beans, snap beans, beets, carrots, corn, okra, peas, pumpkin, spinach, summer squash, and sweetpotatoes—in quart and pint jars, and in No. 2 and No. 2½ tin cans.

Meats and poultry were obtained from the Bureau of Animal Industry at the Agricultural Research Center, Beltsville, Md., and from the commercial market.

Vegetables were obtained from a local market while they were in season. These included vegetables from many regions in the country.

Preparation and Packing

Methods of preparation and packing of the vegetables and meat followed procedures given in departmental publications AWI–93 and AWI–110 (*31, 32*) except where preliminary work made changes seem advisable. (See Appendix, p. 27.) Within the restrictions of laboratory technique, all canning was done as nearly as possible as it would be in the home.

The packed weights of precooked vegetables in pint jars and the drained weights after processing are given in table 2.

Table 2.—*Average packed weight and drained weight for vegetables in pint jars*

Product	Average weight of—	
	Precooked vegetable packed	Drained processed vegetable
	Grams	*Grams*
Asparagus	412	361
Beans, lima	291	360
Beans, snap	338	349
Beets	374	372
Carrots	358	377
Okra, sliced	267	----------
Okra, whole	264	----------
Peas	288	----------
Pumpkin, cubed	400	----------
Pumpkin, mashed	458	----------
Spinach	376	348
Squash, summer	414	367
Sweetpotatoes, dry pack	452	----------
Sweetpotatoes, wet pack	385	416

Rates of Heat Penetration

Temperatures were obtained by means of copper-constantan thermocouples placed in the containers of food at the center of the region which is slowest to heat. Thermocouples were connected to a recording potentiometer. The wires were 24-gauge, duplex enamel covered, and individually glass-wrapped. Thermocouples were made by twisting the two bare wires and soldering the junction, after which the twist was clipped short. The insulation near the junction was wrapped with linen thread and coated with lacquer. Thermocouple wires were sealed into the lid of the canner through a fixture containing

Figure 6.—Pressure canner on heat source, with temperature-measuring equipment assembled as used in the study.

six stuffing boxes. A single stuffing box was made to lead the wires through a metal lid for each glass jar. Stuffing boxes were also used for leading wires into tin cans. Here the nut holding the device in place was soldered to the under side of the lid into which a hole of the proper size had been drilled. The threads were cleared with a tap so that the stuffing box could easily be screwed into the lid. In this way the thermocouple wire did not interfere with the operation of the can sealer.

The sealing temperature of all tin containers was at least 170° F. Filled, unsealed cans, whether packed with hot or cold foods, were placed in a covered boiling water bath with the water level 2 inches below the top of the cans and heated until the temperature at the center reached 170°. Raw meat in glass containers was also treated in this manner. Glass jars packed with hot foods were placed in the canner without further heating. Thermocouples were screwed into the tops of tin cans or were placed in jars which were put immediately in the canner. The arrangement of the temperature-measuring equipment is shown in figure 6.

Aluminum steam-pressure canners of the regular household size holding 16 pint jars, 7 quart jars, 16 No. 2 cans, or 10 No. 2½ or No. 3 cans were used for all processing. In each case a full load of containers was processed. All but quart containers were stacked in two tiers. Jars or cans with thermocouples were distributed so as to be in the center and at the side in each tier.

The canner when loaded contained boiling water. It was operated on a 2,000-watt unit connected through a variable transformer and wattmeter to register the energy input. After the lid had been fastened and the canner temperature reached 212° F., the canner was exhausted for 10 minutes. Temperatures of the containers and the canner were recorded continuously from the time the lid was fastened. Processing time was counted from the instant the canner reached 240°. A canner with pint or quart glass jars or No. 3 cans was removed from the heat source at the end of the process and allowed to cool at room temperature away from drafts. When the canner temperature reached 212°, the lid was removed and the glass jars placed on a table to continue to cool at room temperature. The cans were immersed in a pan of cold water. A canner with No. 2 or No. 2½ tin containers was removed from the heat source at the end of the processing time and the steam pressure released. All cans were removed immediately and immersed in a large pan of cold water, replenished to assure rapid cooling. The cans were rotated to hasten cooling. Recording of the temperature of the food within all containers continued until it was below 190°.

Inoculated Packs

The inoculated packs were carried out essentially as outlined by Williams (*35*). For meat, quart jars packed with pork chunks were used. The jars were the type having glass lids with rubber rings and wire-bail closures. For vegetables, all inoculated packs were run in pint jars with metal closures. In interpreting the results of the inoculated packs, the data on the survival or destruction of the test organism in pork in quart jars and vegetables in pint jars under defined processing conditions have been applied to meats and vegetables in other sizes and types of containers.

The test organism was putrefactive anaerobe No. 3679, isolated by Cameron in 1927 in the laboratories of the National Canners Association (Townsend, Esty, and Baselt, *30*). Since that time it has been widely used in canning laboratories as a test organism for evaluating the adequacy of calculated thermal processes for low-acid canned foods. At 250° F. in phosphate buffer at pH 7.0 the spores of this anaerobe exhibit a resistance to heat somewhat less than twice the maximum resistance reported for *Cl. botulinum* under the same conditions (*30*), and the slopes of the thermal-death-time curves of the two organisms are similar in such media. In most meat and vegetable products this organism grows readily with rapid gas production.

Spore suspensions were prepared by growing No. 3679 in pork extract broth. After incubation for 3 weeks, pork solids were removed by filtration through cheesecloth and the spores concentrated by centrifugation. Vegetative cells were killed by heating suspensions at 185° F. for 10 minutes. Spore counts were made in deep agar in flat culture tubes.

The heat resistance of spore suspensions was checked by thermal-death-time determinations using pyrex thermal-death-time tubes. Corrections of 0.85 minute were deducted from observed heating times

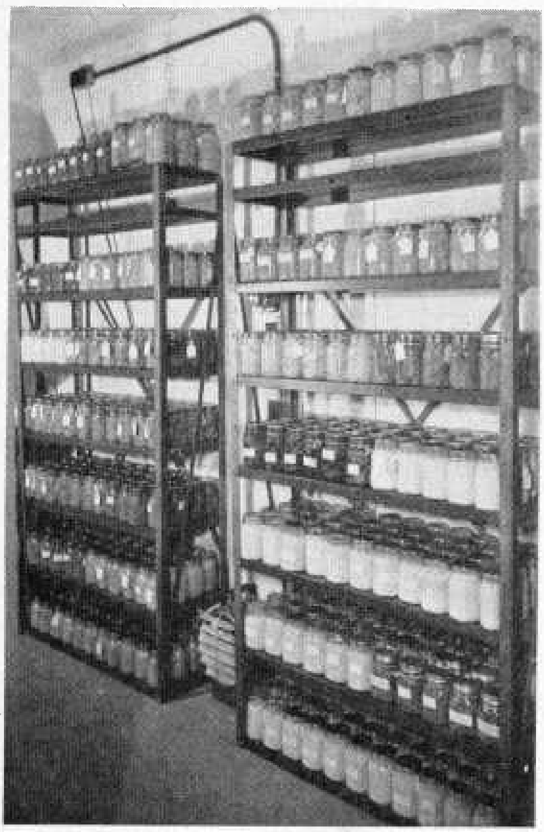

FIGURE 7.—Inoculated and control jars of food under incubation at 86° F.

to correct for heating lag (Sognefest and Benjamin, *25*). In phosphate buffer, pH=7.0, with spore concentrations of 100,000 per milliliter, F and z values of 5.6 and 19.0, respectively, were determined.

Appropriate dilutions of the prepared suspensions were made in sterile water for use in inoculating experimental packs. For the inoculated-pack checks on meat processes, 1 ml. of suspension containing approximately 30,000 spores was injected with a hypodermic needle into a chunk of pork located at the center of the jar. Vegetables in pint jars were inoculated at the jar center with 1 ml. of a 10,000 per milliliter spore suspension.

From preliminary heat-penetration data at least three processes were chosen for making the inoculated-pack check on each product studied. The shortest process was estimated to yield complete or gross spoilage after processing and incubation of inoculated jars and to serve as a check on the thermal resistance of the test suspension. The intermediate and longest processes were estimated to yield little and no spoilage, respectively. For each of the calculated processes the pack consisted of a minimum of 24 inoculated and 12 control jars. Meats were incubated at 98.6° F. and vegetables at 86° F. (fig. 7) for 90 days or longer, during which time jars were checked daily for signs of spoilage. Jars of vegetables which survived incubation were sub-

FIGURE 8.—Bacteriological examination of jars of food after incubation to check for survival of spoilage organisms.

cultured into appropriate media to check for survival of the test organism (fig. 8).

PROCESSES FOR MEATS

The mean process value and standard deviation for 26 jars of pork loin precooked in broth, and processed for 120 minutes at 250° F. by a modification of the method described by Stanley, Stienbarger, and Shank (*26*) were found to be 90.9 and 11.1, respectively. For 26 jars of pork packed raw, exhausted, and processed 80 minutes at 250° by the method described by Cover, Turk, and Kerns (*10*), the mean process value was 48.6 and the standard deviation 11.2. The sterilizing values of these processes are much greater than required to destroy known spoilage organisms.

Reduction of the process temperature from 250° to 240° F. and processing pork loin in quart jars by the procedure described by Stanley, Stienbarger, and Shank (*26*) gave the results shown in table 3.

TABLE 3.—*Process values for pork loin processed at 240° F. in quart jars*

Process time at 240° F.	Jars	Average process value	Standard deviation
Minutes	*Number*	F_0	
135	16	28	3.1
110	6	17	1.2
100	15	16	4.4

From these data process times were estimated for an inoculated pack study for processing at 240° F. Inoculated packs were processed 60, 80, 90, and 100 minutes. Results of this work are given in table 4. After at least 4 months at 98.6° F. the inoculated and control jars were removed from the incubator and held at room temperature. All spoilage of inoculated jars occurred during the first month of incubation and none during an additional 18-month holding period at room temperature. No control jars spoiled. As expected from F_0 values, gross spoilage occurred among the inoculated jars processed 60 minutes, some spoilage among the jars processed 80 minutes, and no spoilage among the jars processed 90 and 100 minutes.

TABLE 4.—*Spoilage of jars of pork inoculated with 30,000 spores of putrefactive anaerobe No. 3679 per quart and of controls after processing in quart jars at 240° F. and incubating at 98.6°*

Process time at 240° F.	Process values				Control jars		Inoculated jars	
	Jars	Mean	Range	Standard deviation	Total	Spoiled	Total	Spoiled
Minutes	*Number*	F_0			*Number*	*Number*	*Number*	*Number*
60	6	4.6	2.3– 6.6	1.6	12	0	24	23
80	7	9.5	5.4–12.6	2.6	14	0	27	4
90	6	9.7	5.9–10.4	1.7	12	0	24	0
100	7	17.2	10.9–21.8	4.1	14	0	27	0

Heat-penetration data were obtained from 73 quart jars of pork processed for 90 minutes at 240° F. The calculated F_0 values ranged from 5.9 to 21.6 with a mean of 15.0 and a standard deviation of 3.8. These values were tested for conformity to the normal distribution and found not to depart significantly from normality. In a normal distribution 99 percent of the items lie within mean plus or minus 2.6 times the standard deviation. The probability of an item falling below mean minus 2.6 times the standard deviation is only 0.005. The experimental values for pork in quart jars were all within this range, the lower limit of which is 5.1. For this reason, the mean minus 2.6 times the standard deviation has been chosen as the lower limit of the range of data to be used for process calculations.

Processes for meats are based on the previously noted inoculated packs and the experimentally determined process values (table 5). The latter data show that 90-minute processes for pork, beef, and chicken without bone in quart jars yielded mean process values ranging from 12.6 to 21.3. In each case the F_O value derived by subtracting 2.6 times the standard deviation from the mean was 5.1 or higher. Since 5.1 is almost twice the F value of 2.8 for *Cl. botulinum* in neutral phosphate, the 90-minute processes may be considered as having wide margins of safety. They are also spoilage-free processes since inoculated packs processed 90 minutes at 240° F. yielded no spoilage.

Processes recommended on the basis of these investigations are presented in table 6, along with those previously recommended by the United States Department of Agriculture.

TABLE 5.—*Process values for meat and poultry in different containers*

Product	Process time at 240° F.	Containers		Process values	
		Kind	Number	Mean	Standard deviation
	Minutes			F_O	
Beef	90	Quart jars	8	12.6	2.9
Chicken	90	do	11	21.3	4.1
	75	do	11	17.2	4.1
Chicken, boned	90	do	8	17.7	3.6
Pork	70	Pint jars	12	11.8	1.5
	90	Quart jars	73	15.0	3.8
	70	No. 2 cans	12	18.3	3.7
	90	No. 3 cans	12	16.2	2.1

TABLE 6.—*Process times at 240° F. for meat and chicken recommended from the reported data and those at 250° previously recommended by United States Department of Agriculture*

Product	Container	Processes	
		Now recommended	Previously recommended
		Minutes at 240° F.	*Minutes at 250° F.*
Beef	Quart jars	90	120
Chicken	do	75	75
Chicken, boned	do	90	120
Pork	Pint jars	75	85
	Quart jars	90	120
	No. 2 cans	65	85
	No. 3 cans	90	120

CALCULATION OF PROCESSES FOR VEGETABLES

A somewhat different technique was employed in using heat-penetration and inoculated-pack data for the derivation of adequate processes for vegetables. With all of the experimental data obtained, it was observed that plotting of F_O values against process times indicated that the relationship between the two variables over the ranges investigated was approximately linear (fig. 5).

In view of that observation, the linear regression line was fitted to the F_O-process-time data for each product, and its standard error of estimate computed. This line of regression is defined by the regression equation, $y_r = a + bx$, in which x equals the process time;

y, the process value; a, the constant locating the line vertically; and b, the slope of the line. A parallel line was then constructed at a distance of 2.6 times the standard error of estimate below the computed regression line (fig. 9). Assuming normal distribution of F_0 values as demonstrated for the meat processing data, the probability of an individual container yielding an F_0 value falling below the lower line is only 0.005. Process times required to yield desired process values were then read from the above curves as indicated in

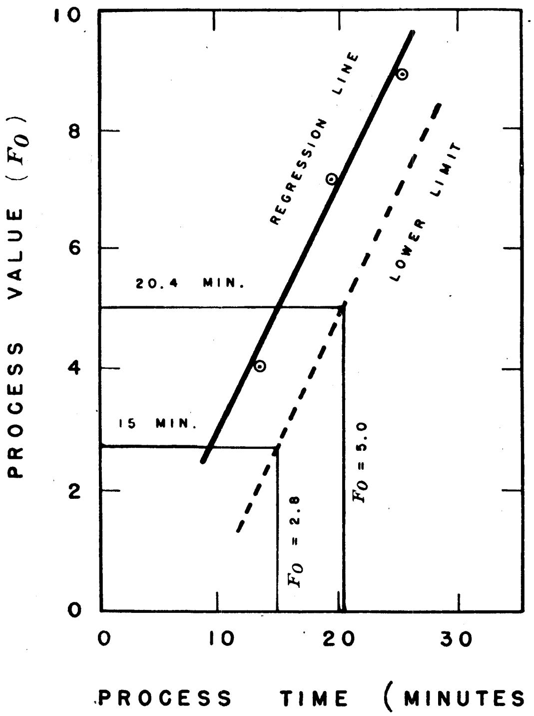

FIGURE 9.—*Regression of process value on process time for 240° F. processes of snap beans in pint jars; parallel constructed at 2.6 times the standard error of estimate below the regression line.*

figure 9. Minimum safe processes are given by the value of the ordinate intersecting at 2.8 the curve showing the chosen lower limit of distribution of the data. These processes cannot, however, be recommended at present because of inadequate information regarding the thermal-death time of *Cl. botulinum* in the various vegetable media.

Values of the process times for pint jars of vegetables and the number of control and inoculated jars which spoiled on incubation appear in table 7. With one exception, none of the control jars spoiled, indicating that the spoilage observed among the inoculated jars was due to the survival and growth of the test organism and not to the fortuitous presence of other equally or more resistant organisms. The exception noted was in a jar of summer squash which spoiled after a 10-minute process at 240° F. Since the average F_0 value of this process was only 2.2, spoilage organisms of moderate resistance might be expected to survive. Spoilage among the inoculated jars was approximately that anticipated from the F_O values of the process times used. Exceptions were noted in peas, lima beans, and corn, where spoilage occurred at F_O values greater than 5.0, and for snap beans and carrots, where no spoilage occurred at 3.9 and 3.0, respectively. These discrepancies were probably due to the variations in thermal-death times and the slopes of the thermal-death-time curves for the test organism in different vegetable media. (See Discussion, p. 21.)

TABLE 7.—*Spoilage of vegetables inoculated with 10,000 spores of putrefactive anaerobe No. 3679 per pint and of controls, after processing in pint jars at 240° F. and incubating at 86°*

Product	Process time at 240° F.	Process values: Number of estimations	Process values: Mean value	Process values: Standard error	Incubation at 86° F.	Control jars: Total	Control jars: Spoiled	Inoculated jars: Total	Inoculated jars: Spoiled	
	Minutes		F_O		*Days*	*Number*	*Number*	*Number*	*Number*	*Percent*
Asparagus	7	7	2.27	0.28	100	12	0	27	26	96
	14	8	4.18	.36	100	12	0	28	2	7
	30	12	9.32	.23	110	12	0	24	0	0
Beans, lima	7	12	3.7	.17	120	12	0	36	36	100
	15	8	5.8	.27	125	12	0	27	13	48
	25	12	9.3	.19	175	12	0	24	0	0
Beans, snap	7	8	1.74	.29	120	12	0	25	13	52
	13	8	3.91	.54	135	12	0	28	0	0
	20	12	7.14	.31	135	12	0	24	0	0
Beets	5	8	2.1	.16	120	12	0	27	1	4
	10	9	2.7	.27	120	12	0	27	2	7
	15	11	5.4	.23	180	12	0	24	0	0
Carrots	6	8	2.06	.36	90	12	0	26	15	58
	9	8	3.04	.32	110	12	0	28	0	0
	15	9	5.46	.32	125	12	0	24	0	0
Corn, cream-style	70	9	12.8	.77	118	12	0	27	0	0
	80	11	15.9	.32	155	12	0	24	0	0
Corn, whole-grain	20	9	5.5	.31	131	12	0	27	21	78
	30	9	7.8	.44	164	12	0	27	6	22
	40	12	10.9	.41	164	12	0	24	2	8
	50	9	15.0	.41	122	12	0	27	0	0
Okra, sliced	5	9	2.3	.13	118	12	0	27	8	30
	10	9	3.5	.28	117	12	0	27	2	7
	20	12	6.5	.27	166	12	0	24	0	0
Okra, whole	5	9	2.5	.14	120	12	0	27	18	67
	10	9	3.2	.34	121	12	0	27	3	11
Peas	15	12	7.3	.18	150	10	0	23	23	100
	25	8	7.5	.41	125	14	0	36	1	3
	30	8	8.5	.27	130	12	0	27	0	0
Pumpkin, cubed	20	9	3.0	.49	89	12	0	27	21	78
	30	8	4.6	.52	86	12	0	27	1	4
	50	12	8.6	.47	96	12	0	24	0	0
Pumpkin, mashed	30	9	3.3	.53	81	12	0	27	4	15
	40	6	3.6	.11	80	11	0	26	1	4
	60	10	8.0	.42	90	12	0	24	0	0
Spinach	25	13	2.15	.16	135	15	0	36	36	100
	30	8	2.46	.15	110	12	0	27	24	89
	35	7	4.41	.30	95	12	0	26	11	42
	38	8	5.03	.31	150	12	0	28	0	0
Squash, summer	10	8	2.2	.29	157	12	1	27	23	85
	15	9	3.5	.47	118	23	0	55	31	56
	20	11	5.6	.34	167	12	0	23	0	0
Sweetpotatoes, dry pack	30	9	3.4	.39	123	12	0	27	4	15
	40	8	4.9	.29	120	12	0	27	0	0
	60	8	9.1	.54	120	12	0	27	0	0
	90	11	18.1	.45	131	12	0	26	1	4
Sweetpotatoes, wet pack	25	9	2.4	.43	130	12	0	27	23	85
	35	9	4.4	.18	136	12	0	27	13	48
	45	12	5.7	.28	141	12	0	24	0	0

Table 8 is a compilation of heating, cooling, and total process values of experimental process times for vegetables in the various containers.

TABLE 8.—*Heating and cooling data and sterilizing values of processes at 240° F. for vegetables in various containers*

Product	Containers		Process time	Packing or sealing temperature [1]	Initial temperature	Process values			
	Kind	Number				Heating	Cooling	Total	Standard deviation
			Minutes	°*F.*	°*F.*	F_H	F_C	F_O	
Asparagus	Pint jars	7	7	--------	217	0.4	1.9	2.3	0.73
		8	14	--------	212	1.1	3.1	4.2	1.02
		12	30	143	226	5.8	3.5	9.3	.84
	Quart jars	12	75	143	201	12.2	3.6	15.8	1.81
	No. 2 cans	12	15	180	234	4.2	1.0	5.2	.44
	No. 2½ cans	12	15	184	235	4.5	.9	5.4	.36
Beans, lima	Pint jars	12	7	--------	227	1.0	2.7	3.7	.59
		8	15	--------	226	2.6	3.2	5.8	.75
		12	25	154	227	5.2	4.1	9.3	.66
	Quart jars	12	50	169	213	8.9	4.4	13.3	2.23
	No. 2 cans	10	30	186	234	8.1	1.0	9.1	.68
	No. 2½ cans	12	30	188	234	7.9	1.1	9.0	.59
Beans, snap	Pint jars	8	7	--------	208	.1	1.6	1.7	.81
		8	13	--------	219	1.2	2.7	3.9	.61
		12	20	154	223	3.6	3.5	7.1	1.08
	Quart jars	15	40	166	220	8.3	2.7	11.0	.90
	No. 2 cans	12	36	183	232	9.7	.8	10.5	.83
	No. 2½ cans	12	46	183	227	11.5	.7	12.2	1.12
Beets	Pint jars	8	5	--------	214	.2	1.9	2.1	.44
		9	10	--------	212	.5	2.2	2.7	.82
		11	15	116	219	1.6	3.8	5.4	.77
		6	30	--------	218	4.2	4.5	8.7	1.73
	Quart jars	11	80	110	199	13.7	5.2	18.9	2.14
	No. 2 cans	11	30	178	225	6.5	1.3	7.8	.85
	No. 2½ cans	11	40	180	222	8.6	1.4	10.0	.79
Carrots	Pint jars	8	6	--------	212	.2	1.9	2.1	1.01
		8	9	--------	216	.5	2.5	3.0	.85
		9	15	163	221	2.0	3.5	5.5	.97
	Quart jars	12	39	176	215	7.6	3.9	11.5	.53
	No. 2 cans	12	30	181	232	8.2	.8	9.0	.57
	No. 2½ cans	12	61	181	231	15.8	.7	16.5	.79
Corn, cream-style	Pint jars	9	70	--------	192	7.1	5.7	12.8	2.32
		11	80	167	181	8.6	7.3	15.9	1.07
	No. 2 cans	11	80	182	193	9.5	1.8	11.3	1.78
Corn, whole-grain	Pint jars	9	20	--------	214	2.0	3.5	5.5	.92
		9	30	--------	212	3.2	4.6	7.8	1.31
		12	40	164	214	5.7	5.2	10.9	1.41
		9	50	--------	218	9.4	5.6	15.0	1.23
	Quart jars	12	80	169	202	13.1	5.7	18.8	2.36
	No. 2 cans	12	50	185	218	11.0	1.5	12.5	1.05
	No. 2½ cans	11	60	177	214	13.2	1.6	14.8	.94
Okra, sliced	Pint jars	9	5	--------	217	.2	2.1	2.3	.40
		9	10	--------	215	.6	2.9	3.5	.85
		12	20	126	215	2.0	4.5	6.5	.94
	Quart jars	12	45	118	201	5.6	5.4	11.0	1.25
	No. 2 cans	12	20	187	223	3.7	1.5	5.2	.56
	No. 2½ cans	12	30	182	221	6.0	1.4	7.4	1.58
Okra, whole	Pint jars	9	5	--------	219	.3	2.2	2.5	.42
		9	10	--------	219	.7	2.5	3.2	1.02
Peas	Pint jars	12	15	164	224	2.4	4.9	7.3	.61
		8	25	--------	220	4.4	3.1	7.5	1.15
		8	30	--------	222	5.5	3.0	8.5	.77
	Quart jars	12	35	184	213	5.1	3.9	9.0	.84
	No. 2 cans	12	20	189	234	5.6	1.1	6.7	.41
	No. 2½ cans	12	15	185	234	4.1	.9	5.0	.34

TABLE 8.—*Heating and cooling data and sterilizing values of processes at 240° F. for vegetables in various containers*—Continued

Product	Containers: Kind	Containers: Number	Process time	Packing or sealing temperature[1]	Initial temperature	Process values: Heating	Process values: Cooling	Process values: Total	Process values: Standard deviation
			Minutes	°*F.*	°*F.*	F_H	F_C	F_O	
Pumpkin, cubed	Pint jars	9	20	--------	198	0.8	2.2	3.0	1.48
		8	30	--------	200	1.5	3.1	4.6	1.48
		12	50	--------	193	4.3	4.3	8.6	1.62
	Quart jars	10	105	168	198	17.0	5.4	22.4	4.15
	No. 2 cans	12	40	186	216	6.3	1.0	7.3	1.78
	No. 2½ cans	12	80	191	208	13.9	1.3	15.2	3.68
Pumpkin, mashed	Pint jars	9	30	--------	195	1.3	2.0	3.3	1.60
		6	40	--------	188	1.0	2.6	3.6	.28
		10	60	165	189	3.4	4.6	8.0	1.32
	Quart jars	8	75	159	189	6.3	3.4	9.7	2.68
	No. 2 cans	12	85	197	198	10.4	1.8	12.2	1.52
	No. 2½ cans	12	95	183	192	8.2	1.4	9.6	1.15
Spinach	Pint jars	13	25	--------	186	.3	1.8	2.1	.59
		8	30	--------	184	.5	2.0	2.5	.42
		7	35	--------	188	1.0	3.4	4.4	.77
		8	38	--------	188	1.3	3.7	5.0	.88
		20	65	170	186	6.5	5.8	12.3	2.01
	Quart jars	13	85	174	189	8.8	4.3	13.1	1.50
	No. 2 cans	12	80	176	204	12.9	1.7	14.6	1.26
	No. 2½ cans	12	105	171	196	16.6	1.4	18.0	2.43
Squash, summer	Pint jars	8	10	--------	208	.3	1.9	2.2	.82
		9	15	--------	210	.8	2.7	3.5	1.41
		11	20	168	207	1.2	4.3	5.5	1.13
	Quart jars	10	50	165	208	8.1	3.7	11.8	1.10
	No. 2 cans	12	10	177	235	2.9	1.1	4.0	.46
	No. 2½ cans	12	20	173	234	5.7	1.2	6.9	.79
Sweetpotatoes, dry pack.	Pint jars	9	30	--------	188	.5	2.9	3.4	1.18
		8	40	--------	184	1.1	3.8	4.9	.83
		8	60	--------	183	4.0	5.1	9.1	1.54
		11	90	155	183	10.4	7.7	18.1	1.51
	Quart jars	11	110	138	167	12.5	5.2	17.7	2.85
	No. 2 cans	12	90	186	195	11.0	2.1	13.1	1.96
	No. 2½ cans	12	100	172	191	12.1	1.0	13.1	3.19
Sweetpotatoes, wet pack.	Pint jars	9	25	--------	193	.6	1.8	2.4	1.30
		9	35	--------	189	.9	3.5	4.4	.53
		12	45	125	174	1.1	4.6	5.7	.98
	Quart jars	12	85	131	172	6.8	6.6	13.4	3.61
	No. 2 cans	12	60	172	210	9.0	1.9	10.9	3.08
	No. 2½ cans	12	75	178	201	9.1	1.6	10.7	3.70

[1] Packing temperature of glass jars; sealing temperature of tins.

For asparagus, beans, beets, carrots, okra, pumpkin, spinach, squash, and sweetpotatoes, process times were chosen to yield F_O values of 5.0. This value was chosen as being adequate for those products on the basis of the inoculated-pack results (table 7). The inoculated-pack results indicated that the test organism is more resistant in lima beans, corn, and peas than in neutral phosphate. For this reason, process times for those products were chosen to yield F_O values, as given in table 9, which were considered adequate on the basis of the inoculated-pack data. The data for process value-process time relationships as shown by the line of regression, the coefficient of regression, and the standard error of estimate for each product are summarized in that table. Calculated process times and recommended process times are included.

TABLE 9.—*Regression equation and standard error of estimate of regression of process value on process time; calculated and recommended process times for vegetables in various containers processed at 240° F.*

Product	Container	Regression equation $Y_r=a+bx$: a	Regression equation $Y_r=a+bx$: b	Regression equation $Y_r=a+bx$: Standard error of estimate	Process value	Calculated processing time at 240 °F.	Recommended processing time at 240 °F.
					Fo	*Minutes*	*Minutes*
Asparagus	Pint jars	+0.172	0.305	0.896	5.0	23	25
	Quart jars	−5.575	.282	1.708	5.0	53	55
	No. 2 cans	+.839	.293	.388	5.0	18	20
	No. 2½ cans	+1.246	.273	.359	5.0	17	20
Beans, lima	Pint jars	+1.100	.314	.662	9.3	32	35
	Quart jars	−1.663	.297	2.285	9.3	57	60
	No. 2 cans	+.805	.278	.659	9.3	37	40
	No. 2½ cans	+.687	.277	.578	9.3	37	40
Beans, snap	Pint jars	−1.149	.409	.841	5.0	20	20
	Quart jars	−.493	.290	.809	5.0	26	25
	No. 2 cans	+.549	.276	.744	5.0	23	25
	No. 2½ cans	−.341	.275	.989	5.0	29	30
Beets	Pint jars	+.884	.275	.939	5.0	24	25
	Quart jars	−4.913	.286	2.268	5.0	55	55
	No. 2 cans	−.227	.267	.823	5.0	28	30
	No. 2½ cans	−1.272	.281	.853	5.0	30	30
Carrots	Pint jars	−.344	.383	.694	5.0	19	20
	Quart jars	−1.671	.342	.793	5.0	25	25
	No. 2 cans	+.780	.277	.466	5.0	20	20
	No. 2½ cans	+.684	.249	.406	5.0	22	25
Corn, cream-style	Pint jars	−14.042	.375	1.594	12.8	83	85
	No. 2 cans	−10.766	.276	1.731	12.8	102	105
Corn, whole-grain	Pint jars	−2.922	.356	1.291	12.8	54	55
	Quart jars	−6.171	.311	2.569	12.8	82	85
	No. 2 cans	−1.294	.276	1.030	12.8	61	60
	No. 2½ cans	−1.715	.275	.846	12.8	61	60
Okra	Pint jars	−.615	.353	.904	5.0	23	25
	Quart jars	−4.042	.333	1.415	5.0	38	40
	No. 2 cans	−.899	.307	.580	5.0	24	25
	No. 2½ cans	−1.604	.300	1.622	5.0	36	35
Peas	Pint jars	−.410	.327	1.356	8.5	38	40
	Quart jars	−1.960	.313	.820	8.5	40	40
	No. 2 cans	+1.108	.278	.394	8.5	30	30
	No. 2½ cans	+.884	.278	.331	8.5	30	30
Pumpkin, cubed	Pint jars	−3.686	.243	1.597	5.0	53	55
	Quart jars	−12.167	.329	4.530	5.0	88	90
	No. 2 cans	−2.382	.242	1.516	5.0	47	50
	No. 2½ cans	−5.664	.261	3.211	5.0	73	75
Pumpkin, mashed	Pint jars	−6.494	.238	1.079	5.0	60	60
	Quart jars	−11.694	.284	2.255	5.0	79	80
	No. 2 cans	−12.606	.291	1.721	5.0	76	75
	No. 2½ cans	−17.359	.282	.912	5.0	88	90
Spinach	Pint jars	−5.832	.287	.680	5.0	44	45
	Quart jars	−13.140	.307	1.439	5.0	71	70
	No. 2 cans	−6.311	.253	1.314	5.0	58	60
	No. 2½ cans	−4.294	.184	1.805	5.0	76	75
Squash, summer	Pint jars	−.740	.305	1.036	5.0	28	30
	Quart jars	−3.539	.306	1.085	5.0	37	40
	No. 2 cans	+1.173	.278	.457	5.0	18	20
	No. 2½ cans	+1.306	.278	.771	5.0	20	20
Sweetpotatoes, dry pack	Pint jars	−6.857	.263	1.857	5.0	63	65
	Quart jars	−15.928	.306	3.115	5.0	95	95
	No. 2 cans	−11.826	.277	1.862	5.0	78	80
	No. 2½ cans	−11.444	.245	2.639	5.0	95	95
Sweetpotatoes, wet pack	Pint jars	−2.473	.179	.912	5.0	55	55
	Quart jars	−15.791	.343	3.674	5.0	88	90
	No. 2 cans	−5.752	.278	3.059	5.0	67	70
	No. 2½ cans	−7.558	.244	3.294	5.0	87	90

DISCUSSION

Processes for canned foods are adequate when every particle of food within the container has been raised to a lethal temperature and held at that temperature for a sufficient length of time to kill the most resistant spoilage organism present. As pointed out in the introduction, it is possible to calculate thermal processes for canned foods which are just adequate to destroy any known spoilage organism. Such computations are predicated upon accurate definitions of the thermal-death time and slope of the thermal-death-time curve of the organism in question, and upon the number of individuals present, i. e., the bacterial load. Of the two types of information required for such process calculations, heat-penetration data can be obtained under rigorously controlled conditions and the various factors affecting it can be defined with considerable accuracy. The bacteriological data required cannot, at present, be described with equal precision and thus they introduce incompletely defined constants into process computations. Because of this lack of basic data, it becomes necessary to select from available information, bacterial load and thermal-death-time data which err, if at all, in the direction of yielding processes which are longer than necessary.

For medium- and low-acid foods which are subject to spoilage by toxin-producing *Cl. botulinum*, processes, to be safe, must be at least adequate to destroy the spores of that organism. Previously cited work of Esty and Meyer (*14*) with spore suspensions in phosphate buffer at pH=7.0 defined the ideal thermal-death-time curve of *Cl. botulinum* with F and z values of 2.78 and 18, respectively. Subsequent investigations have, in general, tended to confirm these values with minor corrections. In other media such as foods, however, z values may vary several degrees on either side of the ideal. Townsend, Esty, and Baselt (*30*) have, for example, reported z values ranging from 13.4 to 15.6 for the thermal-death-time curves of *Cl. botulinum* in four food media. Such differences will introduce considerable variation into F_0 values derived from process calculations. Nevertheless, it has been customary, except where definitely contraindicated, to use $z=18$ for process calculations, and in the absence of sufficient more reliable information, that value has been used here.

When each of a number of F_0 values are computed for a given product from independent heat-penetration measurements, it may be expected that these values will be randomly distributed about the mean. Since the mean F_0 will be greater than the minimum value observed, the difference depending upon the distribution of the data, it is evident that choice of processes based on mean F_0 values would frequently lead to the derivation of inadequate processes.

The lowest process value experimentally obtained could, with some reason, be chosen as the lower limit below which spoilage might be expected. When the sample of F_0 values available is limited to 12 to 20 items, it is very probable that a larger sample would yield values below the lowest observed. Thus, it is necessary to choose a safe process represented by an F_0 value which the data indicate will be attained or exceeded by almost all of the containers processed. For the processes computed here, that lower limit has been chosen as the process value represented by an F_0 which is 2.6 times the standard error of estimate below the mean observed F_0. Assuming normal distribution of observed F_0 values, expected values would not fall below that limit more than once among each 200 containers of food processed.

The above outlined choice of a lower limit for process values which on the surface allows for over-all spoilage of 0.5 percent would be highly questionable in the absence of other safety factors. The more significant of these factors are the heat resistance of the test organism and the technique of the inoculated-pack checks on calculated processes.

While information is very limited, there is good reason to believe that the spores of the test organism, putrefactive anaerobe No. 3679, are of definitely greater resistance than those of commonly encountered soil forms which might cause spoilage. Conn (*9*) noted that soil suspensions heated at 85° C. for 15 to 20 minutes gave spore counts averaging approximately 50 percent of counts made after heating suspensions at 75° for the same periods of time. These results indicate a low order of heat resistance for the spores of many soil forms. Tischer and Esselen (*29*) reported thermal-death times of four organisms isolated from spoiled low-acid foods. All had F values below that of No. 3679 in phosphate buffer at pH 7.0 and in two foods.

That the test organism in the concentration used exhibits greater resistance than is characteristic of normal contamination is also shown by the results reported here. Of a total of 653 control jars of meats and vegetables processed as part of the inoculated packs, only 1 jar spoiled, even after short processes which permitted gross to 100 percent spoilage of inoculated jars (tables 4 and 7).

In addition, the number of spores used for inoculated packs was somewhat in excess of the normally expected natural spore load. The choice of inoculum and its concentration by placement at the slowest heating point of the container, thus insuring maximum probability of survival, constitute additional safety factors.

Processes recommended on the basis of these investigations are presented in table 10 along with those previously recommended by the United States Department of Agriculture and by commercial processors. In every instance processes for vegetables in pints are shorter than those previously recommended. For quarts, however, the data obtained have led to the derivation of longer processes in a few instances and over-all process reductions have not been as great as for pints. This is probably related directly to packing and processing techniques. The data of table 8 show that the initial temperatures of quart packs were generally below those of pints. The effect of lower and more variable temperatures and other factors affecting processes in quart and pint containers are illustrated by the data of table 9. For a majority of the vegetables, the standard error of estimate of observed F_0 values was considerably higher with quarts than with pints. Lower initial temperatures and larger error estimates both lead to the derivation of longer processes by the applied procedure.

TABLE 10.—*Process times at 240° F. for vegetables: Recommended from the reported data, previously recommended by United States Department of Agriculture, and by commercial processors*

Product	Container	Process time at 240° F.		
		Recommended from data	Previous United States Department of Agriculture [1]	Commercial [2]
		Minutes	*Minutes*	*Minutes*
Asparagus	Pint jars	25	*35	
	Quart jars	55	*40	
	No. 2 cans	20		25
	No. 2½ cans	20		25
Beans, lima	Pint jars	35	*45	
	Quart jars	60	*55	
	No. 2 cans	40	40	35
	No. 2½ cans	40	[3] 50	
Beans, snap	Pint jars	20	*30	
	Quart jars	25	*40	
	No. 2 cans	25	30	20
	No. 2½ cans	30		25
Beets	Pint jars	25	*40	
	Quart jars	55	*45	
	No. 2 cans	30	30	30
	No. 2½ cans	30	[3] 30	30
Carrots	Pint jars	20	*40	
	Quart jars	25	*45	
	No. 2 cans	20	30	30
	No. 2½ cans	25	30	30
Corn, cream-style	Pint jars	85		
	No. 2 cans	105		[4] 90
Corn, whole-grain	Pint jars	55	*65	
	Quart jars	85	*75	
	No. 2 cans	60	50	50
	No. 2½ cans	60	[3] 65	
Okra	Pint jars	25	*35	
	Quart jars	40	*40	
	No. 2 cans	25	25	17
	No. 2½ cans	35	[3] 30	
Peas	Pint jars	40	*45	
	Quart jars	40		
	No. 2 cans	30	40	35
	No. 2½ cans	30		
Pumpkin, cubed	Pint jars	55	*85	
	Quart jars	90	*105	
	No. 2 cans	50		
	No. 2½ cans	75		
Pumpkin, mashed	Pint jars	60		
	Quart jars	80		
	No. 2 cans	75		[4] 70
	No. 2½ cans	90		[4] 95
Spinach	Pint jars	45	*95	
	Quart jars	70	*105	
	No. 2 cans	60		
	No. 2½ cans	75		
Squash, summer	Pint jars	30	*85	
	Quart jars	40	*105	
	No. 2 cans	20		
	No 2½ cans	20		
Sweetpotatoes, dry pack	Pint jars	65		
	Quart jars	95		
	No. 2 cans	80		[4] 85
	No. 2½ cans	95		[4] 95
Sweetpotatoes, wet pack	Pint jars	55	*100	
	Quart jars	90	*110	
	No. 2 cans	75	95	
	No. 2½ cans	90	[3] 115	

[1] Processes marked by * are from AWI-93, others from Farmers' Bulletin 1762, United States Department of Agriculture.
[2] Processes from bulletin 26-L, National Canners Association.
[3] No. 3 cans.
[4] Closing temperature specified as 180° F.

Differences between processes recommended for glass and tin containers are not as great as, and frequently not in the direction, anticipated. General considerations would indicate shorter processes for foods in glass under home-canning conditions than in tin containers of similar capacity. Since glass containers must cool slowly, the cooling period may be expected to contribute substantially more to the lethal value of the process than when tins are used and the temperature is reduced rapidly. This is illustrated by the data of table 8 which show that for vegetables processed in pint jars the process value of the cooling period averaged 50 percent of the total process value as compared with 15 percent for processes in No. 2 tins. Similarly, for quart jars and No. 2½ tins, the F_C values as percentages of F_O averaged 36 and 11 percent, respectively. In contrast to the results expected on the above basis, comparison of the pint jar and No. 2 tin processes recommended (table 10) shows that in 6 of 15 instances, processes for pints are equal to or greater than those recommended for No. 2 tins. Only three processes for quarts are shorter than those recommended for the same products in No. 2½ tins. This failure of the longer cooling period for foods processed in glass to be reflected in generally shortened process times must be related to initial temperatures.

In tin containers which were exhausted and sealed at 170° F. or above, the initial temperatures were generally higher than with glass containers of similar capacity which were packed hot and processed without exhausting (table 8). These higher initial temperatures could account for the generally lower error estimates of observed F_O values obtained from processes using tin containers (table 9). Thus, with the experimental procedures used, the higher and more uniform initial temperature of tin packs tended to balance the increased process values resulting from slow cooling of glass packs.

With the exceptions noted, the processes recommended have been designed to yield F_O values of 5.0 or higher on the assumption that thermal-death-time curves of spoilage organisms to be destroyed have slopes of $z=18$. With greater z values, the chosen process value would be attained in shorter processing times. Lesser z values would yield correspondingly longer processes. As has been noted, information is available which shows that the thermal-death times and slopes of thermal-death-time curves of *Cl. botulinum* and other spoilage organisms vary with the media in which the organisms are heated. Because of this variation, processes which are adequate without being excessive must ultimately be based upon data regarding the thermal characteristics of spoilage organisms in each product for which a process is to be established. Sufficient information of this nature is not available at present, and processes must be based largely upon phosphate-buffer, thermal-death-time data.

The reported data indicate that processes based on inoculated packs with putrefactive anaerobe No. 3679 are more severe than necessary to destroy the natural spore load normally present on vegetables and meats as prepared for home canning. They provide evidence for suspecting that home-canning-process times may be safely based on lower sterilizing values than are considered necessary in commercial canning. Much additional information is necessary, however, before that question can be properly evaluated. Absence of adequate data on normal spore loads and the resistance of spoilage organisms in different food media make it necessary to choose processes which are probably excessive in many instances. Further reductions may be justified when sufficient experimental data are obtained which will define more precisely the heat resistance and slopes of thermal-death-time curves of spoilage organisms in various food media.

LITERATURE CITED

(1) Ball, C. O.
1923. THERMAL PROCESS TIME FOR CANNED FOOD. Natl. Res. Council Bul., vol. 7, no. 37, 76 pp., illus.

(2) ———
1928. MATHEMATICAL SOLUTION OF PROBLEMS ON THERMAL PROCESSING OF CANNED FOOD. Calif. Univ. Pubs., Pub. Health 1 (2): 15–245, illus.

(3) Bigelow, W. D.
1921. THE LOGARITHMIC NATURE OF THERMAL DEATH TIME CURVES. Jour. Infect. Dis. 29: 528–536, illus.

(4) ——— Bohart, G. S., Richardson, A. C., and Ball, C. O.
1920. HEAT PENETRATION IN PROCESSING CANNED FOODS. Natl. Canners Assoc., Res. Lab. Bul. 16–L, 128 pp., illus.

(5) ——— and Esty, J. R.
1920. THE THERMAL DEATH POINT IN RELATION TO TIME OF TYPICAL THERMOPHILIC ORGANISMS. Jour. Infect. Dis. 27: 602–617, illus.

(6) Burns, C. M.
1932. RATE OF HEAT PENETRATION. I AND II. STUDIES IN THE RATE OF HEAT PENETRATION IN CERTAIN HEAT-STERILISED FOODS. Food Technol. 1: 348–351, illus.; 400–402, illus.

(7) Cameron, E. J.
1936. DEVELOPMENT OF THE CANNING INDUSTRY. Canning Trade 59 (6): 18, 20–21, 32.

(8) ———
1938. RECENT DEVELOPMENTS IN CANNING TECHNOLOGY WITH REFERENCE TO SPOILAGE CONTROL. Food Res. 3: 91–99.

(9) Conn, H. J.
1916. ARE SPORE-FORMING BACTERIA OF ANY SIGNIFICANCE IN SOIL UNDER NORMAL CONDITIONS? Jour. Bact. 1: 187–195.

(10) Cover, S., Turk, R. D., and Kerns, A. H.
1943. DEVELOPMENT OF METHODS FOR SAFE PROCESSING OF HOME CANNED MEATS. Tex. Agr. Expt. Sta. Bul. 635, 21 pp., illus.

(11) Dickson, E. C., Burke, G. S., Beck, D., and others.
1922. STUDIES ON THE THERMAL DEATH TIME OF SPORES OF CLOSTRIDIUM BOTULINUM. Amer. Med. Assoc. Jour. 79: 1239–1240.

(12) Esselen, W. B., Jr.
1945. BOTULISM AND HOME CANNING. Mass. Agr. Expt. Sta. Bul. 426, 28 pp., illus.

(13) ———, and Tischer, R. G.
1945. HOME CANNING. II. DETERMINATION OF PROCESS TIMES FOR HOME-CANNED FOODS. Food Res. 10: 215–226, illus.

(14) Esty, J. R., and Meyer, K. F.
1922. THE HEAT RESISTANCE OF THE SPORES OF B. BOTULINUS AND ALLIED ANAEROBES. Jour. Infect. Dis. 31: 650–663, illus.

(15) ——— and Williams, C. C.
1924. HEAT RESISTANCE STUDIES. I. A NEW METHOD FOR THE DETERMINATION OF HEAT RESISTANCE OF BACTERIAL SPORES. Jour. Infect. Dis. 34: 516–528, illus.

(16) Jackson, J. M.
1940. MECHANISMS OF HEAT TRANSFER IN CANNED FOODS DURING THERMAL PROCESSING. Inst. Food Technol. Proc., pp. 39–50, illus. Champaign, Ill.

(17) ——— and Olson, F. C. W.
1940. THERMAL PROCESSING OF CANNED FOODS IN TIN CONTAINERS. IV. STUDIES OF THE MECHANISMS OF HEAT TRANSFER WITHIN THE CONTAINER. Food Res. 5: 409–421, illus.

(18) LANCEFIELD, S.
1933. PROBLEMS OF HEAT TRANSFER IN CANNING. Food 3: 48–50, illus.

(19) MAGOON, C. A., and CULPEPPER, C. W.
1921. A STUDY OF THE FACTORS AFFECTING TEMPERATURE CHANGES IN THE CONTAINER DURING THE CANNING OF FRUITS AND VEGETABLES. U. S. Dept. Agr. Bul. 956, 55 pp., illus.

(20) ——— and CULPEPPER, C. W.
1922. RELATION OF INITIAL TEMPERATURE TO PRESSURE, VACUUM, AND TEMPERATURE CHANGES IN THE CONTAINER DURING CANNING OPERATIONS. U. S. Dept. Agr. Bul. 1022, 52 pp., illus.

(21) NELSON, C. I., and BERRIGAN, D.
1939. EFFECTIVENESS OF HEAT PENETRATION IN THE CANNING OF MEAT IN THE HOME BY THE PRESSURE COOKER. Jour. Agr. Res. 59: 465–474, illus.

(22) ——— and KNOWLES, D.
1940. EFFECTIVENESS OF HEAT PENETRATION IN MEAT CANNED IN GLASS JARS IN A PRESSURE COOKER. Jour. Agr. Res. 61: 753–759, illus.

(23) OLSON, F. C. W., and STEVENS, H. P.
1939. THERMAL PROCESSING OF CANNED FOODS IN TIN CONTAINERS. II. NOMOGRAMS FOR GRAPHIC CALCULATION OF THERMAL PROCESSES FOR NON-ACID CANNED FOODS EXHIBITING STRAIGHT-LINE, SEMI-LOGARITHMIC HEATING CURVES. Food Res. 4: 1–20, illus.

(24) SCHULTZ, O. T., and OLSON, F. C. W.
1940. THERMAL PROCESSING OF CANNED FOODS IN TIN CONTAINERS. III. RECENT IMPROVEMENTS IN THE GENERAL METHOD OF THERMAL PROCESS CALCULATIONS—A SPECIAL COORDINATE PAPER AND METHODS OF CONVERTING INITIAL AND RETORT TEMPERATURES. Food Res. 5: 399–407, illus.

(25) SOGNEFEST, P., and BENJAMIN, H. A.
1944. HEATING LAG IN THERMAL DEATH-TIME CANS AND TUBES. Food Res. 9: 234–243, illus.

(26) STANLEY, L., STIENBARGER, M., and SHANK, D.
1942. HOME CANNING OF FRUITS, VEGETABLES, AND MEATS. U. S. Dept. Agr. Farmers' Bul. 1762, 46 pp. (Rev. ed.)

(27) THOMPSON, G. E.
1919. TEMPERATURE-TIME RELATIONS IN CANNED FOODS DURING STERILIZATION. Indus. and Engin. Chem. 11: 657–664, illus.

(28) ———
1922. HEAT FLOW IN A FINITE CYLINDER HAVING VARIABLE SURFACE TEMPERATURE. Phys. Rev. (ser. 2) 20: 601–606, illus.

(29) TISCHER, R. G., and ESSELEN, W. B., JR.
1945. HOME CANNING. I. SURVEY OF BACTERIOLOGICAL AND OTHER FACTORS RESPONSIBLE FOR SPOILAGE OF HOME-CANNED FOODS. Food Res. 10: 197–214.

(30) TOWNSEND, C. T., ESTY, J. R., and BASELT, F. C.
1938. HEAT-RESISTANCE STUDIES ON SPORES OF PUTREFACTIVE ANAEROBES IN RELATION TO DETERMINATION OF SAFE PROCESSES FOR CANNED FOODS. Food Res. 3: 323–346, illus.

(31) UNITED STATES BUREAU OF HUMAN NUTRITION AND HOME ECONOMICS.
1944. HOME CANNING OF FRUITS AND VEGETABLES. U. S. Dept. Agr. AWI–93, 16 pp., illus.

(32) ———
1945. HOME CANNING OF MEAT. U. S. Dept. Agr. AWI–110, 16 pp., illus.

(33) WEISS, H.
1921. THE HEAT RESISTANCE OF SPORES WITH SPECIAL REFERENCE TO THE SPORES OF B. BOTULINUS. Jour. Infect. Dis. 28: 70–92, illus.

(34) ———
1921. THE THERMAL DEATH POINT OF THE SPORES OF BACILLUS BOTULINUS IN CANNED FOODS. Jour. Infect. Dis. 29: 362–368, illus.

(35) WILLIAMS, O. B.
1940. EXPERIMENTAL PROCEDURE FOR PROCESS DETERMINATION FOR CANNED FOODS. Inst. Food Technol. Proc., pp. 323–327. Champaign, Ill.

APPENDIX

Methods Used for Preparing, Precooking, and Packing Vegetables and Meats Into Containers

LOW-ACID VEGETABLES

Asparagus.—Only the tender part of asparagus stalks was used. The scales were trimmed from the stalks to eliminate sand. The stalks were cut into inch pieces, covered with boiling water, and boiled 3 minutes. Asparagus was packed hot and covered with hot cooking liquid.

Beans, lima.—Fresh young, tender beans were shelled, covered with boiling water, and brought to a boil. They were packed hot, covered with fresh boiling water.

Beans, snap.—Beans were cut into inch pieces, covered with boiling water, and boiled 5 minutes. They were packed hot and covered with hot cooking liquid.

Beets.—Beets were sorted and prepared separately according to size. Tops were trimmed off, leaving 1 inch of stem. Baby beets were boiled 15 minutes, medium size 20 minutes, and large beets 25 minutes, to loosen their skins. After being skinned and trimmed, baby beets were packed hot and covered with fresh boiling water. All other beets were cut into ½-inch slices, halved or quartered for uniformity. They were packed hot and covered with fresh boiling water.

Carrots.—Carrots were cut lengthwise in quarters or smaller, depending on the size, and then cut crosswise into ½-inch pieces. The pieces were covered with boiling water and precooked 5 minutes, packed hot, and covered with the hot cooking liquid.

Corn, cream-style.—Corn was cut from the cob at about the center of the kernel, and the cob scraped. Boiling water was added in the proportion of 1 pint of water to 2 pints of corn. The mixture was brought to a boil and packed hot. No extra liquid was added.

Corn, whole-grain.—Corn was cut from the cob as close as possible without including bits of the cob. Boiling water was added in the proportion of 1 pint of water to 2 pints of cut corn. The mixture was brought to boiling and packed hot. No extra liquid was added.

Okra.—Only tender pods of okra were used. The trimmed pods were blanched for 1 minute in boiling water and packed whole or cut into 1-inch pieces and then packed. Fresh boiling water was used to cover the vegetables in the container.

Peas.—Shelled green peas were covered with boiling water and brought to a boil. They were packed hot and covered with fresh boiling water.

Pumpkin, diced.—Pumpkin was peeled and cut into 1-inch cubes. Three quarts of pumpkin to 1 quart boiling water were brought to a boil. The diced pumpkin was packed hot and covered with hot cooking liquid.

Pumpkin, mashed.—Pumpkin was peeled and cut into 1-inch cubes. It was steamed until tender and pressed through a food mill. The strained mixture was heated to 190° F. and packed hot with no salt and no added liquid.

Spinach.—Tough stems and midribs were cut out of freshly picked, tender spinach. About 2½ pounds of trimmed, thoroughly washed greens were placed in a cheesecloth bag and steamed in a large, closed vessel for about 10 minutes or until well wilted. They were packed hot, loosely, and covered with boiling water.

Squash, summer.—Half-inch slices of summer squash, halved or quartered for uniformity of size, were covered with boiling water, brought to a boil, packed hot, and covered with the hot cooking liquid.

Sweetpotatoes, dry pack.—Sweetpotatoes were sorted according to size and steamed separately, 20 minutes for small ones, 25 minutes for the medium size, and 30 minutes for large sweetpotatoes. They were peeled, cut into lengthwise pieces, and packed. Sweetpotatoes were packed solid with no liquid and no salt added.

Sweetpotatoes, wet pack.—Above directions were followed to the point of packing pieces in jars. Boiling water was used to cover the vegetable.

Meats

Pork.—Lean pork was cut from the bones, trimmed of excess fat, cut into chunks, and precooked until medium done in broth made from the bones.

Quart glass jars were packed with meat, care being taken to place a chunk of meat so that its center would be just below the center of the jar. The method of procedure for pint jars of pork loin was the same as for quart jars.

For canning pork loin in No. 2 and No. 3 tin cans, the raw, trimmed loin was cut into chunks approximately the height of the can. The meat was packed solid, level with the top of the can, with the grain of the meat running vertically. The cans were exhausted in boiling water to a depth of within 2 inches of the tops of the cans until the temperature of the chunk of meat at the center of the can was 170° F. Enough juice was released by the meat to fill the can. Any loss of liquid in exhausting was replaced with boiling water just before the can was sealed.

Beef.—Beef was canned in quart jars using the same technique as described for pork.

Chicken.—Chicken with part of the bone removed was canned in quart jars. The meat was removed from the breastbone. The meaty pieces—thighs, second wing joints, and wishbone—were packed with the bone. The drumsticks were cut off short. The packing was such that a half breast occupied the center of each jar. Chicken precooked in broth was packed hot; raw packs were exhausted before processing.

Boned chicken was prepared both by cutting the raw meat from the bones, and by removing the meat from the bones after it had been precooked in broth. Only the meaty pieces were used.

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